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CAST ALUMINIUM ALLOY

The present invention relates to a cast aluminium alloy suitable particularly for thermally highly stressed cast parts. By using the cast aluminium alloy according to the invention, the efficiency of cast parts produced therefrom is improved considerably, their thermal stability being guaranteed up to temperatures of 400EC.

By means of modern casting methods, such as the diecasting method, the sand casting method, the permanent-mold casting method or the thixocasting and rheocasting method, which are very far developed technically, highly stressable cast parts can currently be produced from aluminium alloys.

By means of diecasting, cast parts, for example, can be produced which meet high demands with respect to quality. However, the quality of a diecast part depends not only on the machine adjustment and the selected method but to a great extent also on the chemical composition and the structure of the used cast alloy. It is known that the two latter parameters influence the castability, the feeding behavior, the mechanical characteristics and, which is particularly important in diecasting, the useful life of the casting tools.

The alloy development per se has therefore again become more important in the automobile and airplane construction in order to achieve the desired characteristics of the components by means of special alloy compositions.

From the state of the art, a plurality of compositions for cast aluminium alloys are known.

European Patent Document EP 0 687 742 A1, for example, discloses a diecast alloy on an aluminium silicon base, which contain 9.5 - 11.5 % in weight silicon, 0.1 - 0.5 % in weight magnesium, 0.5 - 0.8 % in weight manganese, max. 0.15 % in weight iron, max. 0.03 % in weight copper, max. 0.10 % in weight zinc, max. 0.15 % in weight titanium as well as a remainder of aluminium and a permanent finishing with 30 to 300 ppm strontium.

From European Patent Document EP 0 792 380 A1, an aluminium alloy is known which consists of 5.4 - 5.8 % in weight magnesium, 1.8 - 2.5 % in weight silicon, 0.5 - 0.9 % in weight manganese, max. 0.2 % in weight titanium, max. 0.15 % in weight iron and aluminium as the remainder with further impurities to an individual max. of 0.02 % in weight and totally maximally 0.2 % in weight, which are suitable particularly for thixocasting or thixoforging.

Furthermore, from European Patent Document EP 1 229 141 A1, a cast aluminium alloy is known, which is suitable mainly for permanent mold casting and sand casting, and contains at least 0.05 - 0.5 % in weight manganese, 0.2 - 1.0 % in weight magnesium, 4 - 7 % in weight zinc and 0.15 - 0.45 % in weight chromium.

However, these cast aluminum alloys are conceived mainly for safety-relevant vehicle components, such as control arms, supports, frame parts and wheels, in the case of which a high ductile yield is primarily in the foreground. These alloys are not suitable for thermal stresses of up to 400EC. The classical cast

aluminium alloys are thermally stable only up to approximately 200EC.

From the article by Feikus et al. "Optimization of a Cast AlSi Alloy and Application-Oriented Development of the Casting Practice for Producing Highly Stressable Engine Blocks", Giesserei (Foundry) 88 (2001), No. 11, Pages 25-32, an AlSi7MgCuNiFe alloy is known which is conceived especially for cast engine parts.

Also, from International Patent Document WO A-96/10099, aluminium alloys containing scandium are known for increasing the stability. The high stability is a result of an artificial aging after a solution heat treatment and quenching with water. It is a disadvantage that a distortion occurs as a rule during the solution heat treatment, which distortion has to be corrected by additional measures or operating steps (measuring and aligning).

It is an object of the present invention to develop a cast aluminium alloy which is suitable for thermally highly stressed cast parts. In this case, the high-temperature stability, that is the thermal stability, of the mechanical characteristics is to be ensured up to temperatures of 400EC. Furthermore, the cast aluminium alloy according to the invention should have a good weldability and should be producible by means of a plurality of methods while the castability is good.

This object is achieved by means of a cast aluminium alloy which consists at least of

1.0 - 8.0 % in weight magnesium (Mg),

> 1.0 - 4.0 % in weight silicon (Si),

0.01 - < 0.5 % in weight scandium (Sc),

0.005 - 0.2 % in weight titanium (Ti),

0 - 0.5 % in weight of an element or an element group selected from the group consisting of zirconium (Zr), hafnium (Hf), molybdenum (Mo), terbium (Tb), niobium (Nb), gadolinium (Gd), erbium (Er) and vanadium (V),

0 - 0.8 % in weight manganese (Mn),

0 - 0.3 % in weight chromium (Cr),

0 - 1.0 % in weight copper (Cu),

0 - 0.1 % in weight zinc (Zn),

0 - 0.6 % in weight iron (Fe),

0 - 0.004 % in weight beryllium (Be),

the remainder of aluminium and further impurities to an individual max.of 0.1 % in weight and totally maximally 0.5 % in weight.

The magnesium content in this case is preferably between 2 - 7 % in weight, particularly preferably between 3 - 6 % in weight.

The silicon content is advantageously between 1.1 - 4.0 % in weight, particularly advantageously between 1.1 - 3.0 % in weight.

The addition of scandium is essential. In addition to an intensive particle hardening, the scandium causes a grain refining of the cast structure and a recrystallization inhibition as a result of the thermally very stable Al_3Sc particles. Cast parts produced from the alloy according to the invention, therefore have the

advantage that their mechanical characteristics are stable up to temperatures of 400EC. The cast alloy according to the invention is therefore predestined mainly for thermally highly stressed cast parts. It is also advantageous, that, as a result of the high thermal stability, a replacement of aluminium materials by materials of a high density is not required. By the use of the alloy according to the invention, the component weight is guaranteed while the conductivity is increased, which component weight can even be reduced by cast parts which have thinner walls. It is another advantage that the weldability is also improved by means of the scandium fraction. The scandium content is preferably between 0.01 - 0.45 % in weight, particularly preferably between 0.015 - 0.4 % in weight.

Like scandium, titanium also causes a grain refining and therefore contributes in a corresponding manner to the improvement of the thermal stability. In addition, titanium lowers the electric conductivity. The titanium content preferably amounts to between 0.01 - 02 % in weight, particularly between 0.05 - 0.15% in weight.

Since zirconium has the same effect as scandium or titanium, it is also advantageous to additionally admix zirconium to the alloy. The effect of the scandium of causing an intensive particle hardening by the thermally very stable Al_3Sc particles, a grain refining of the structure as well as a recrystallization inhibition is further increased by the combined effect of scandium and zirconium. Zirconium substitutes Sc atoms and forms particles of the ternary compound $Al_3(Sc_{1-x} Zr_x)$ which have less of a tendency to coagulate at higher temperatures than the Al_3Sc particles. The scandium and zirconium constituents again improve

the thermal stability of the alloy in comparison to an alloy which contains only scandium. This permits a further optimization in the direction of lower scandium contents for lowering the cost. The zirconium content of preferred embodiments is between 0.01 - 0.3 % in weight or 0.05 - 0.1 % in weight.

In addition to the increase of thermal stability by adding scandium, titanium and possibly zirconium, there is the advantage that the cast aluminium alloy already has the thermal-stability-increasing effect as cast. As a result of the subsequent heat treatment in a temperature range of typically 250 - 400EC, the mechanical characteristics with the corresponding thermal stability are finally achieved, By means of the appropriate selection of the temperature and the time duration - as known, the time duration depending on the component size and thickness -the thermal stability can be varied correspondingly. A solution heat treatment with a subsequent artificial aging is not required, which is advantageous in that the problem concerning the distortion will not play any role, which distortion usually requires a measuring and aligning and, as known, occurs in the case of classical solution-heat-treated and artificially aged cast aluminium alloys.

In addition to the zirconium or instead of the zirconium, hafnium, molybdenum, terbium, niobium, gadolinium, erbium and/or vanadium may be added to the alloy. According to an alternative embodiment, the alloy contains one or more elements selected from the group consisting of zirconium, hafnium, molybdenum, terbium, niobium, gadolinium, erbium and vanadium. In this case, the sum of the selected elements amounts to maximally 0.5 % in weight, preferably, however, 0.01 - 0.3 % in weight.

However, it is particularly advantageous for the alloy to contain at least 0.001% in weight, preferably at least 0.008 % in weight vanadium. Vanadium acts as a grain refiner, similarly to titanium. Furthermore, it improves the weldability and reduces the scratching tendency of the molten material.

According to another alternative embodiment, the alloy contains at least 0.001 % in weight gadolinium.

For the further optional alloy constituents chromium, copper and zinc, the following content ranges are preferred:

Chromium: 0.001 - 0.3 % in weight, particularly 0.0015 - 0.2 % in weight
copper: 0.001 - 1.0 % in weight, particularly 0.5 - 1.0 % in weight
zinc: 0.001 - 0.1 % in weight, particularly 0.001 - 0.05 % in weight.

It is known that by adding iron and/or manganese, the adhesive effect is reduced. Preferably, a manganese content of maximally 0.01 % in weight and an iron content of from 0.05 - 0.6 % in weight is used. The technical iron content is typically at least 0.12 % in weight. However, the addition of iron and/or manganese is not absolutely necessary for permanent mold casting and sand casting.

In contrast, an addition of iron and/or manganese is required for the diecasting method in order to reduce the adhesive effect of the diecast part in the mold. In the case of cast aluminium alloy, the manganese content for the diecasting is preferably between 0.4 - 0.8 % in weight. In addition, the sum of the manganese

and iron content should amount to at least 0.8 % in weight. However, it is particularly advantageous for the diecast alloy to contain either only iron or only manganese.

Additional advantages, characteristics and details of the cast aluminium alloy according to the invention as well as their characteristics are contained in the following description of preferred embodiments.

Examples:

From three different alloys, sample rods for determining the mechanical characteristics were cast by means of the permanent Diez rod mold. In addition to scandium and titanium, the first alloy also contains zirconium. The second alloy has a higher scandium content than the first alloy but contains no zirconium. The third alloy is a variant with a higher magnesium and silicon content.

In addition, a fourth alloy, which also contains copper, was produced by means of diecasting. This alloy was obtained by melting in a 200 kg electrically heated crucible furnace. The casting temperature was 700EC. The casting took place on a 400 t (tension holding force) diecasting machine. A plate of the measurements 220 x 60 x 3 mm was used as the sample shape. Sample rods for tension tests were taken from the plates. The sample rods were machined only on the narrow sides.

A reference alloy (alloy 5) containing neither scandium nor zirconium was used for comparison purposes. This alloy was also cast by means of a permanent

Diez rod mold. The respective alloy compositions are summarized in Table 1.

Table 1: Alloy Compositions

Alloy ng	Alloy Compositions (wt.-%)									
	Si	Cu	Fe	Mn	Mg	Cr	Zn	Ti	V	Zr	Sc
1	1,11	0	0,065	0,1	3,09	0,001	0,002	0,149	0,036	0,076	0,15
2	1,11	0	0,066	0,103	3,34	0,001	0,005	0,122	0,033	0	0,4
3	2,49	0	0,08	0,06	5,6	0	0	0,118	0,19	0,08	0,15
4	2,35	0,001	0,078	0,69	5,59	0,001	0,001	0,1	0,044	0,06	0,17
5 (Ref.)	1,1	0	0,081	0,004	3,036	0,001	0,003	0,129	0,03	0	0

The mechanical characteristics of the different alloys according to the invention cast by means of a permanent Diez rod mold were measured as cast, after a 3-hour heat treatment at 300EC and subsequently at different thermal stresses (200E/500h, 250EC/500h, 350EC/500h and 400EC/500h), for determining the thermal stability. The mechanical characteristics of alloy 4 (diecast alloy) were measured only as cast and after a 1-hour 300EC heat treatment. The reference alloy was subjected to a conventional annealing. The reference alloy was solution treated at 540EC for 12 hours; was then quenched with water and was then artificially aged at 165EC for 6 hours. The measuring results are summarized in Table 2, Rp0.2 being the yield strength in MPa, Rm being the tensile strength in MPa, and A5 being the breaking tension in %.

The tests show that the alloy according to the invention already has good mechanical characteristics as cast. By means of a heat treatment (here, 300EC for 3 hours or 300EC for 1 hour), the mechanical characteristics are further increased, which is a result of particle hardening by segregation from the oversaturated solid solution during "artificial aging"; thus the formation of secondary precipitations $Al_3(Sc_{1-x} Zr_x)$. In addition, the thermal stability of alloys 1 - 3 up to temperatures of 400EC is easily recognizable. Particularly the values for the yield strength and the tensile strength are quite high up to temperatures of 400EC. When comparing the measured values of the reference alloy at 250EC with the corresponding values of the alloy according to the invention, it can clearly be recognized that very good mechanical characteristics are retained in the case of the alloy according to the invention. In contrast, the reference alloy already exhibits a clear reduction of the yield strength and of the tensile strength at 250EC.

In addition to the thermal stability up to temperatures of 400EC, the alloy according to the invention has a very good weldability. It has an excellent casting behavior and can be produced by means of conventional casting methods (diecasting, sand casting, permanent mold casting, thixocasting, rheocasting or derivatives of these methods).

The alloy according to the invention is preferably used for thermally highly stressed cast parts. These are, for example, cylinder heads, crankcases, components for air conditioners; structural airplane parts, particularly for supersonic aircraft, engine segments, pylons, which are highly stressed connection components between the engine and the wings, and the like.

Table 2: Mechanical Characteristics

Alloy	Casting Mold	Heat Treatment	Mechanical Characteristics		
			Rp0.2 [MPa]	Rm [MPa]	A5 [%]
1	Diez	as cast	105	229	13,8
1	Diez	300 °C/3h	200	272	8,6
1	Diez	300 °C/3h & 200 °C/500h	196	270	8,4
1	Diez	300 °C/3h & 250 °C/500h	202	279	8,1
1	Diez	300 °C/3h & 350 °C/500h	149	241	11,5
1	Diez	300 °C/3h & 400 °C/500h	105	201	13,5
2	Diez	as cast	124	202	3,9
2	Diez	300 °C/3h	274	315	2,7
2	Diez	300 °C/3h & 200 °C/500h	253	295	1,9
2	Diez	300 °C/3h & 250 °C/500h	236	285	3
3	Diez	as cast	100	240	8,1
3	Diez	300 °C/3h	207	290	4
3	Diez	300 °C/3h & 200 °C/500h	215	296	3,8
3	Diez	300 °C/3h & 250 °C/500h	212	294	3,6
3	Diez	300 °C/3h & 350 °C/500h	178	278	5,7
3	Diez	300 °C/3h & 400 °C/500h	135	245	11,4
4	die-casting	as cast	194	335	15,8
4	die-casting	300 °C/1h	247	349	9,9
5 (reference)	Diez	540 °C/12h/w/165 °C/6h	184	270	13,8
5 (reference)	Diez	& 200 °C/500h	161	226	14,1
5 (reference)	Diez	& 250 °C/500h	87	180	17,7